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SPACE PHOTOGRAPHY AND ITS GEOGRAPHICAL APPLICATIONS

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UNPUBLISHED PRELIMINARY DATA

Most geographers have at some time sought the highest point in an area from which to study the land. With the invention of aircraft, this approach was extended by personal observation from the air and then on a vast scale by the use of air photographs. In the past fifteen years, higher platforms have become available with the development of high altitude rockets and artificial satellites.

Space photography is, in one sense, an extremely high altitude form of aerial photography and there exist photographs taken from all the intermediate heights. Although photographs from aircraft have mainly been taken from heights of less than about 10 km. (33,000 ft.), some have been taken from at least 31 km. (19 miles).[1] Photographs have been

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1. Yale Katz in Proceedings of the First Symposium on Remote Sensing of Environment, Feb. 1962, Institute of Science and Technology, University of Michigan, 1962 , p. 102.

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obtained from balloons up to at least 30 km. (98,000 ft.)[2]. Most rocket

2. Melvin H. Douglas: Evaluation of high altitude 70 mm. balloon photography, U.S. Naval Photographic Interpretation Center, PIC 221/58-U, TED PIC PH-47234, 1958, p. 2.
See also Eugene P. Griffin: Strato Lab Balloon Photography, Photogrammetric Eng., Vol. XXIII, 1957, pp. 582-587, and Albert W. Stevens: Scientific results of the world-record stratosphere flight, Nat. Geog. Mag., Vol. 69, with photographic supplement, May 1936, pp. 693-714; A.W. Stevens, Andrews and Briggs: Technical details of the record-breaking balloon-flight of Explorer II, Nat. Geog. Scientific Monograph, 1936.

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photographs have been from heights below 150 or at the most 250 km., although some have been obtained from as high as 1400 km. (750 naut. mi.). The majority of photographs from satellites are from heights between 150 and 800 km. Thus, despite the photography from intermediate heights, space photographs in general are obtained from heights about 100 times greater than those used for ordinary aerial photography and it is only to be expected that the problems and potentialities of space photographs differ in several important respects from those of aerial photography.[3]

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3. General articles on the principles of earth photography from satellites are Katz (1), Lowman (2), Rosenberg (3), Merifield (4), Ockert (5).

A major problem in space photography that does not occur in aerial photography is how to recover the pictures that have been taken. One solution is to take the pictures on photographic film and to return the film to earth, either in an armored casette for a 'hard' landing, or in a spacecraft capsule, such as used by astronauts, for a 'soft' landing. The majority of photographs listed in Table I were recovered in this way. An alternative is to take the pictures with a television camera and transmit them back to earth either directly or after storage on a tape. This is the method that has been used by the Tiros satellites to obtain hundreds of thousands of photographs. A combination of these methods was used in the Russian Lunik III to obtain photographs of the other side of the moon.[4]

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4. The Other Side of the Moon, Issued by the USSR Academy of Sciences, Trans. by J.B. Sykes, Pergamon Press, (New York, 1960). N.P. Barabashov, A.A. Mikhailov, and Yu N. Lipskiy, Eds: Atlas of the other side of the moon, First Pub. by USSR Academy of Sciences, Trans. into English by Leon Ter- oganian, Pub. by Pergamon Press, (New York, 1961).

An important difference between space and aerial photographs is the area covered by a single frame. Satellite cameras used to date have taken photographs covering 100 to 1000 km. along a side when directed vertically, and larger areas when obliquely. With such photographs, major distribution patterns over the earth's surface, which are normally only discovered after long periods of fieldwork or air photo interpretation, may be visible at a glance.

Small scale is the price usually paid for the large coverage of space photographs. Photographs so far obtained from satellite heights (over 160 km.) have all been on scales smaller than 1:1,000,000. Inevitably fine detail, such as the user of air photography is accustomed to find, is lacking.

Stereo-images can be obtained using appropriate pairs of space photographs. They may be of value in interpretation because they have better resolution than single photos, but since the three-dimensional effect produced by a given relief varies in inverse proportion to the camera height, other things being equal, space photographs are poorer than air photos for distinguishing height differences, by a factor of at least 10 and often 100 or more. Even so, the stereo-effect is often large enough to separate clouds from land surfaces.

Photography from a satellite has some definite advantages which partially offset the problems mentioned above. Changes of position and orientation of the orbiting camera between exposures are strictly regular; vibration may be absent; and camera systems of long focal length can be accommodated more conveniently than in an aircraft because of the absence of air resistance to the motion of a satellite.

Other problems of mapping from space photographs are introduced by the curvature of the earth, which is clearly visible on single frames, and by atmospheric effects, which reach their maximum since the camera is outside the atmosphere. These include the reduction of tone contrast, and the blueish rendering of colors, both caused mainly by atmospheric scattering. Since 75% of the air and most of the dust particles and water vapor are in the troposphere below about 11 km., these problems should not be much greater in space photographs than in high altitude aerial photographs, except perhaps near the horizon where the light rays are passing obliquely through the earth's atmosphere. Slight distortion is also produced by atmospheric refraction of oblique rays, but is negligible for most purposes. The effects of shimmer and scintillation, caused by rapid variations of air density, are also believed to be negligible except for cameras comparable in size to astronomical telescopes.[5] None of these atmospheric effects

5. O'Keefe et al.(33), Strees (6), A.H. Faulds and R.H. Brock: Atmospheric refraction and its distortion of aerial photographs, presented at Amer. Soc. Photogrammetry meeting, Sept. 1963; R.M.L. Baker Jr. and P.M. Merifield: Effect of atmospheric refraction on the position of terrestrial objects viewed from space, Astrodynamics Research report No. 14, Lockheed-California Co., Oct. 1962.

seems to present insurmountable obstacles to photography from space for geographic purposes.

From the geographer's point of view perhaps the greatest problem in using satellite photographs is the extent of the cloud cover. Aerial photographs cover sufficiently small areas that is possible - albeit with long delays - to choose a time when the area is clear of cloud. Rocket photographs are also often confined to relatively small areas, and the time of launching can be chosen so that the pictures taken show the ground fairly free of cloud. On the other hand when using satellites in orbit it is quite impossible to choose a period when the entire orbit is cloud-free. Indeed, one feature revealed by the photographs is just how much of the earth's surface is usually covered by cloud. It is probable that the use of satellites for comprehensive space photography will be greatest in areas which are typically cloud-free, namely deserts, and the polar regions in spring.

INVENTORY OF SPACE PHOTOGRAPHY[6]

Rocket photography (excluding project Mercury).

For a decade, from 1946 to 1956, the only generally available space photographs were obtained from rockets fired and recovered from the White Sands Proving Ground in New Mexico. During the 1946-1958 period at least 36 rockets, including captured German V2 rockets, the Viking rockets produced when the supply of V2s was exhausted, and the smaller American Aerobee rockets carried cameras for earth photography. Rarely was photography the main purpose of a flight. Usually photographs were taken in order to plot the orientation of the rocket in flight. Cameras were installed in the rockets under the direction of several agencies, of which the Applied Physics Laboratory of Johns Hopkins University has most fully documented the photographic results. The cameras used black-and-white, infra-red and color films in 16 mm, 35 mm, and 4" x 5" sizes with a number of different filters. The camera lenses ranged from wide angle to semi-telephoto. The greatest heights reached were usually 100 to 150 km., though the later Vikings exceeded 200 km. The cameras usually operated throughout most of the rocket trajectory and many of the photographs were from lower altitudes. Photographs were obtained with the camera pointing in all directions.

Many of the photographs are quite clear but the 16 mm films are grainy when enlarged to a convenient viewing size. 2x enlargements from the best of the photographs are not quite as sharp as contact prints of good aerial photographs. A period of fine weather was usually chosen

6. This inventory is restricted to photographs obtained from heights above 80 km. by non-Russian, non-military vehicles.

for firing the rockets and the majority of photographs are fairly free of cloud. Several hundred photographs were obtained from the firings. The areas depicted are limited because the rockets had to rise almost vertically from the White Sands range and only New Mexico and the surrounding states are shown in detail, although points up to about 1000 km. distant in all directions appear towards the horizon on numerous photographs. Repeated photography of the same area has the advantage that the appearance of the vegetation and the extent of the snow cover can be compared at different seasons and in succeeding years. Among the features visible are various types of desert surface, including the White Sands, lava beds (fig. 1) and outcrops of other rocks, mountain ranges and intervening basins, forests, the Rio Grande with its irrigated areas, and at some times of the year snow covering the higher areas. Under optimum conditions railroads, highways, towns and airfields can be seen. The photographs could be used to illustrate a variety of geographical features in the southwest U.S.A.; especially conspicuous is the alternation of basins and ranges and the contrast in vegetation between them.[7]

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7. Holliday (9) contains the largest selection of these photographs. Holliday (7) gives the most technical account. Strip prints of this series are held by the Johns Hopkins University group.

The most valuable firings from White Sands were Viking 11 and 12 which were designed primarily for photography and which produced the highest quality space photographs that are available.

Viking 11 was fired in May 1954. The camera exposed thirty-nine 4" x 5" frames on infra-red film at heights up to 255 km. (158.4 miles), half as high again as any taken before. The photographs were oriented from nearly vertical to high oblique, and point in many directions from above White Sands Proving Ground, although south towards northern Mexico seems to have been preferred. On the highest photographs the horizon is over 1600 km. distant. The amount of cloud varies but frequently photographs are almost clear of cloud. The photographs have high definition. Features visible are in general the same as those on other photographs taken from White Sands but because of the greater altitude a more comprehensive view of the broad features of the landscape can be obtained.

Viking 12, fired in February 1955, used a similar camera and film. As a result of further refinements in the camera setting and the clearer winter atmosphere the photographs are even sharper and are comparable with the best aerial photographs. The fifty-three photographs taken point mainly westwards from White Sands, and are comparatively free of cloud. The pictures illustrate well both the general and detailed characteristics of the Basin and Range landscape in the southwestern U.S.A. (Fig. 2). The gully pattern dissecting the mountain areas is especially well shown. Interesting features which can be picked out in the extreme distance are the cultivated area of the Imperial Valley and the smoke pall over Los Angeles.[8]

8. Baumann & Winkler (15 & 16) contain eleven photographs from Viking 11, and eleven from Viking 12. Requests for copies of the photographs should be addressed to Technical Information Officer, U.S. Naval Research Laboratory, Washington 25, D.C.

A further series of nearly 400 photographs was obtained from White Sands in 1963 from an Aerobee rocket fired to a height of 182 km. (113 mi). They were taken by two 70 mm cameras, using infra-red film, and produced negatives of quality equal to that of the Viking 12 photos (Fig. 3). With them it is possible to make comparisons over the 10 to 15-year period since the earlier photos.[9]

9. Copies of these photographs are held by George MacVeigh, Sounding Rocket Division, N.A.S.A., Goddard Space Flight Center, Greenbelt, Md.

Until Project Mercury, the purpose of all space photography from areas other than White Sands was to photograph cloud patterns from above. Consequently on these pictures there are only small areas of cloud-free land. The Tiros weather satellites were developed as a result of this series of photography.

The first of these rockets was the Nike-Cajun no. 4 rocket, fired from Wallops Island on the coast of Virginia in July 1956, which took photographs from heights up to 113 km. (370,000 ft.)[10]

10. Newell (13)

Photographs were taken from three sounding rockets fired to about 120 km. (75 st. mi.) from Fort Churchill, Canada in July and November 1958 by the Ballistics Research Laboratory, Aberdeen, Md., as part of the IGY program. 35 mm motion-picture cameras with black-and-white film were used. One of the flights produced moderately sharp pictures, some of which showed the ground and perhaps floating ice.[11]

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11. Information supplied by L.F. Hubert.

Good photographs of cloud patterns were obtained by the 16 mm black-and-white cameras carried by the Project HUGO rocket fired in December 1958 to 137 km. (86 st. mi.) from Wallops Island, but small areas of the Virginia coast were the only cloud-free land visible.[12]

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12 Hubert (17)

Two series of photographs taken in May and July 1959 at heights up to 585 km. (316 naut. mi.) proved that satisfactory photographs can be obtained from within the Van Allen radiation belts using standard photographic emulsions, and without special shielding. They were obtained with a 16 mm movie camera on black-and-white film carried in two Thor missiles fired from Cape Kennedy. The theoretical resolution of the system at maximum height was about 2/3 km. on the ground and consequently the pictures could not show great detail. One of the flights produced sharp pictures of cloud patterns along the 1500 mile range southeast from Cape Kennedy and of the Florida coast although they are not of great geographic interest.[13]

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13. Lathrop & Rush (18); Hubert, personal comm.

The highest space photographs of the earth's surface were obtained from an Atlas rocket in August 1959 on 16 mm black-and-white film. The rocket was fired in a southeasterly direction from Cape Kennedy, and took photographs to a point in mid-Atlantic northeast of the mouth of the Amazon River. The greatest height reached was about 1400 km. (750 naut. mi.). The camera swept round the horizon five times during the flight, so that all photographs are high obliques. Much of the area photographed was covered by cloud, but there are some small areas of land free of cloud in northern Florida, parts of the West Indies, and the coast of South America. Because of the cloud and low definition, this is not a promising series of photographs for geographic purposes.[14]

14. Hubert, Fritz and Wexler (19) contains two mosaics of this series. The original negative is held by the General Electric Company. Duplicate prints are held at the National Weather Satellite Center.

Further space photographs of subarctic areas were taken by five Aerobee rockets fired from Fort Churchill, Canada, in September and October, 1960 and May, 1961. 70 mm cameras were used with various combinations of black-and-white, infra-red and color film, and different filters including a polarising filter to aid in distinguishing clouds from ice and snow. The maximum height reached by the rockets ranged from 76 to 225 km. (47 to 140.1 st. mi.). Most photographs include the horizon. Good quality space photographs were obtained on one of the flights, but the aim of the project was to photograph cloud systems and a large part of the ground is obscured. Small parts of a few photographs are of geographical interest; for example, the September photographs illustrate the characteristic terrain of the Canadian Shield, while the May photographs show sea-ice, open water along the shore, and snow-covered lakes and tundra.[15]

15. Evans et al.(22) and Hempfling et al.(23) include fourteen photographs. Copies of the photos may be obtained from Technical Information Division (Code 250), Goddard Space Flight Center, Greenbelt, Md., or may be examined by arrangement with Robert C. Baumann at Goddard Space Flight Center.

Project Mercury photographs.

The remaining space photographs on film were all taken in connection with Project Mercury. The program included orbital flights, in which the capsule became a temporary earth satellite, and sub-orbital flights in which it was launched from Cape Kennedy, Florida and recovered from the Atlantic a few hundred kilometers to the southeast. The Mercury flights yielded three types of photograph. Several of the capsules carried

70 mm 'earth and sky' cameras which took photographs automatically through the window of the spacecraft at intervals of a few seconds throughout the flight. Some capsules included a 16 mm camera which took photographs through the periscope. In capsules which carried astronauts, design and weight limitations restricted earth photographs to 35 mm or 70 mm hand-held cameras. Details of the flights which obtained photographs of the earth are given in Table I.

Of the sub-orbital flights, MR-2 produced the most interesting photographs of the earth. A 70 mm camera took color photographs automatically every 6 seconds throughout the flight. These photographs show Florida, the Bahama Islands, and adjacent areas of shallow water, as well as parts of the Atlantic Ocean. A few photographs taken during flight MR-3 have been published in color but show mainly clouds.[16] MA-4, MA-5

16. Jackson (25)

and MA-9 produced the most interesting photographic results from orbital flights.

The MA-4 photographs were the first generally available pictures of the earth on film recovered from an earth satellite. The camera took 70 mm color photographs automatically every 6 seconds from lift-off until the film was exhausted. During this time the unmanned spacecraft passed from Cape Kennedy across the North Atlantic Ocean, North and Central Africa, and part of the Indian Ocean. Once the spacecraft was in orbit, all photographs taken pointed northeast and included the horizon. The first part of the film shows mainly the North Atlantic Ocean and the clouds above it. During the final exposures from about Lake Rudolph onwards, the earth was in darkness and no ground detail is visible. Between the Lake Chad area and Lake Rudolph much of the earth's surface is obscured by broken clouds, though ground detail is visible through the gaps. It is only between the Moroccan coast and Lake Chad (frames 182 to 270) that continuous areas of land are visible. These photos show the major geographical features of southern Morocco, southern Algeria and parts of Niger and southern Libya. They include landforms developed under desert conditions on horizontal, tilted, gently and intensely folded strata (fig. 4); longitudinal (fig. 5) and transverse sand-dunes; dry water courses; rocky, sandy, and gravelly desert surfaces; clay plains and salt flats; pediments with inselbergs; and the transitions of vegetation from desert to sub-desert steppe, wooded steppe, and savanna.[17]

17. Black-and-white photographs and an analysis of their contents are contained in Morrison and Chown (26). Two color photographs are contained in Weaver and Sisson (27).

The MA-5 photographs were also taken by an automatic camera mounted in an unmanned capsule. On this flight, the interval between frames was increased to 33 seconds and the film was not exhausted until near the end of the second orbital pass. All photographs point west and include the horizon. Many of the photographs were taken over ocean areas, during the hours of darkness, or over land areas obscured by cloud or dense haze. About 25 frames reveal distinct tone variations on the ground. Among areas and features visible are parts of the western Sahara immediately southwest of those in the MA-4 photos; the area round the lower Senegal River, showing dune belts and the desert-savanna transition; basin-and-range topography in northwestern Mexico; and drainage, vegetation and land use patterns in the Mississippi floodplain (fig. 6) and southeastern U.S.A.

On the manned orbital flights, MA-6 to MA-9, photographs of the earth were taken by cameras held by the astronauts. During the first three of these flights there was considerable cloud cover, and only a few photographs of cloud-free land areas were obtained. On flight MA-9 Astronaut Cooper was more fortunate and obtained more than 30 pictures of land areas, scattered over the belt from about 30°N to 30°S traversed by the spacecraft. Features shown include landforms and geology in the deserts of Arabia, Iran and N.W. India, glaciers in the Himalayas, snow-cover and geological structure in Tibet, and land use and submarine depth patterns in the Ganges delta area. Because of the variety of landscape photographed, this series is probably the most useful for assessing the potentialities of space photography for geographical purposes.[18]

18. The fullest account of photography on the later Mercury-Atlas flights is contained in O'Keefe *et al.*(33). With a few exceptions, Project Mercury photographs are unclassified and persons interested in obtaining copies should enquire from the Public Information Office, National Aeronautics and Space Administration, Washington 25, D.C., U.S.A.

Tiros Photography.

A system involving radio transmission to the earth of satellite photographs has been developed for Tiros. Between April 1960 and the end of 1963, seven Tiros satellites were launched and for practically the whole period at least one was producing usable pictures. Tiros was designed to obtain pictures of the cloud cover of the earth for meteorological purposes. Each satellite carries two television cameras pointing in the same direction. The system is sensitive to light of wave lengths 0.45 to 0.8 microns,[19] which is intermediate between panchromatic and infra-red photographic emulsions. The Tiros satellites travel in orbits which lie mainly between 650 and 850 km. above the earth and circle the earth about once every hundred minutes. The nature of the orbit confines the areas photographed to between the 55th parallels for Tiros I to IV, and from about 65°N to 65°S for Tiros V to VII.

When a Tiros satellite is within range of one of the two command-and-data-acquisition stations in the United States, television pictures can be relayed directly from the satellite and are recorded. Pictures taken of other parts of the world are stored on tape until the satellite is within range of one of these stations and are then relayed to earth. Photographs are taken only when the cameras are pointing towards part of the earth that is in daylight. They are taken at intervals of either 10 seconds or 30 seconds. Different types of lens have been used in the different Tiros models (Table I). The 104° or wide-angle lens gives a picture 1000 km. square when the camera is pointing directly downwards. The 75° or medium-angle lens gives a picture about 700 km. square, and the 12.67° or narrow-angle lens gives a picture about 100 km. square (see figs. 7 to 10).

The factor limiting the resolution of the system is the width of the television scan line.[20] When the camera is pointing directly downwards,

19. Fritz & Wexler (42), p. 1.

20. C.O. Erickson and L.F. Hubert: Identification of cloudforms from Tiros I pictures, U.S. Dept. of Commerce, Weather Bureau, Meteorological Satellite Laboratory Report No. 7, June 1961.

this is equivalent to 3 km. at the earth's surface for wide angle cameras, to 2 km. for medium angle and to 1/3 km. for narrow angle. The quality of the pictures tends to deteriorate towards the end of the life of each Tiros. Tiros II is of limited value to geographical research as the wide-angle camera went out of focus and the narrow-angle pictures are difficult to locate. Tiroses IV, V and VI may be the most useful, since their cameras have an improved grey scale, and each has one medium-angle lens.[21]

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21. There is a voluminous literature on Tiros photography and satellites. An exhaustive bibliography to 1962 is contained in Kiss (35). Items 40 & 41 are collections of articles on Tiros. Articles particularly relevant to geographical research include items 42 to 53. The prime depository of Tiros pictures is the U.S. National Weather Records Center, Arcade Building, Asheville, N.C. where the pictures are stored chronologically on hundred-foot reels of 35 mm film. Copies may be obtained either in positive or negative form from this address. Orders must be placed for one or more complete reels at a cost of $6 each.

Catalogues have been published for Tiros I to IV.[22] With the

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22. Catalogues (36, 37, 38, 39) may be obtained from Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C.

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exception of the Tiros II catalogue they include maps which show the area covered by each sequence of photographs. They also indicate the reel on which each sequence can be found. In the case of Tiros V, VI and VII which are or were until recently operational, the place of these catalogues is filled by monthly preprints.[23] They include the same

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23. Preprints are obtainable on request from the Documentation Section, National Weather Satellite Center, Federal Office Building 4, Suitland, Md.

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information as the published catalogues except that the reel numbers are not shown. The coverage maps in the catalogues and preprints for Tiros IV and later also show the extent of the cloud cover on each sequence, so that it is possible to select sequences showing cloud-free land areas. Cloud analyses for Tiros I, II and III are available on a separate microfilm.

To allow more accurate location of features in individual frames, overlays with a latitude and longitude graticule or 'grid' are being prepared for a certain number of frames in almost all usable sequences. These are already available on microfilms from National Weather Records Center for Tiros I and III. In the grid microfilms for Tiros I pictures, each grid appears superimposed on the picture to which it applies. The microfilms of grids for Tiros III and later contain only the grids, so that the user is free to try to improve the fit of grid to picture if he wishes.

THE GEOGRAPHICAL APPLICATIONS

The rapid extension of aerial photography in the last two decades has introduced a radically new element into many branches of geographical research. It is natural to wonder whether the development of space photography will produce a similar revolution. Space photographs have two main advantages over air photographs. If short focal length lenses are used, the scale will be small (typically smaller than 1:1,000,000) and large areas of the earth's surface will be visible on a single frame. In a suitable situation it may be possible to see on one photograph changes of soil and vegetation resulting from zonal climatic variations. Cover patterns not previously recognized may also be revealed at these scales. Space photography may provide a low-cost means of repetitive photography of a chosen area once a space platform has been established.

Apart from its obvious illustrative value in teaching and writing, the best use of space photography for geographers is likely to be found in distribution mapping of natural and human phenomena. These include static features that vary little from one year to the next such as landforms, shallow submarine forms including underwater deltas and coral reefs, glaciers, major vegetation groups, and some types of land utilization. Other distribution patterns are dynamic and vary over annual or shorter periods; they include the distribution of sea, lake and river ice, snow, the extent of lakes, swamps and rivers in arid areas, forest and savanna fires, and crop changes. Few of these objectives can be achieved with existing space photography.

Each Tiros has taken about 30,000 frames but only a small percentage are of geographical interest. A remarkably high proportion of the earth's surface is usually obscured by cloud and at least half the cloud-free areas are over the ocean, so it is only on a small minority of the frames that any land is visible at all. For these reasons methodical search is required to find frames showing land areas on which there are tone differences due to variations in the type of land surface. Tiros photographs are taken from a considerably greater height than most of the photographs on recovered film, and by a method of inherently low resolution so that only broad outlines on the earth's surface such as coastlines and large lakes are generally visible. Other features that have been recognized include the limits of snow cover (Fig. 10), lake and river ice (Fig. 7), the boundary between rock and sand areas in deserts, (Fig. 9), belts of sand dunes in deserts, areas of vegetation and cultivation within otherwise arid areas, and the limits of forests.

Some of the better Tiros photographs show snow, sea ice and burnt areas in northern forests (from the snow visible on the ground) and projects are already underway to make use of these potentialities.[24]

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24. Singer & Popham, (45), Watanabe (46).

Tiros photographs have been used successfully to trace changes in ice cover on the Gulf of St. Lawrence[25] and snow cover in the Sierra Nevada

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25. Wark et al., (47, 48), Canada, Defense Research Board, (50), Baliles and Neiss, (49).

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of California.[26]

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26. Tarble, (51).

The longest continuous sequence of recovered satellite photographs suitable for geographical purposes is the MA-4 film across North Africa. Major landforms and geological patterns are obvious. Although the area has already been mapped on scales comparable to that of the photographs they enable more detail to be added than was known previously. The photographs also show vegetation distribution in some areas but unfortunately just as the flight path brings inhabited areas into view cloud intervenes. In fact, some of the isolated photographs taken by Cooper on flight MA-9 may be geographically more useful than the MA-4 photos.

If this analysis of the geographic usefulness of space photography is only moderately optimistic, it is because it refers only to existing space photography. No photographs have been taken for a specific geographic purpose. The Tiros photographs are designed for meteorological uses with quite different requirements, and do not cover the polar latitudes where they may be of greatest geographical value. The Mercury photographs were taken on color film with small, relatively simple cameras and only cover a small part of the earth's surface. The specifications for a good aerial survey are usually stringent on such factors as scale, overlap, type of film, filter, the angle of acceptance of the lens , the weather conditions, the acceptable cloud cover, the time of day and the time of year. In the same way one cannot expect to get the best out of space photography unless the values of essentially the same factors are chosen to bring out the specific features which are of interest.

The future holds great promise. In the design of future satellite camera systems, aims should include improved ground resolution,both with and without the maintenance of present angles of view, more systematic camera orientation, more systematic and more frequent coverage. Small improvements might be made merely by more careful choice of system components, for example film and filter. Moderate improvements in these directions would require higher priority for photographic experiments in the allocation of weight and space in satellites. This could permit a larger camera, or more film, attitude control fuel or electric power, any or all of which could contribute to improved ground resolution, coverage, or timing. Large improvements would present engineering problems, but there is no reason to think they are insoluble. Plans have already been announced for the launch of between 10 and 20 manned and unmanned satellites during the next five years which are definitely, or potentially camera platforms. The geographical usefulness of the results obtained will depend in part on the interest shown by possible users before the designs are far advanced.

In summary, though space photography is not likely to lead to a complete revolution in geographical methods, the geographer should be prepared to add very soon to the sources of information he regularly consults - books, maps, air photographs, and personal field notes - a new source, space photographs.

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Table I. Summary of Space Photography

Vehicle	Date	Heights from which photos taken, H km	Focal length, f mm. (Note 2)	Scale number of original if vertical, H/f, millions	Frame size, mm. (Note 3)	Angle of view, degrees (Note 2)	Film (Note 4)	Regions photographed	Published references (Note 5)
Rocket photography									
V2's, Aerobees, early Vikings, about 35 rockets in all	1946-1958	Mainly <168	35	<4.8	10.5x7.5	21	B/W, IR, color	S.W. U.S.A., north Mexico	7-14
			50	<3.4	24.5x18	33			
			163	<1.0	127x102	53			
Viking 11	24 May 54	53-255	163	.33-1.6	127x102	53	IR	S.W. U.S.A., north Mexico	15
Viking 12	4 Feb 55	142-230	163	.87-1.4	127x102	53	IR	Arizona & adjacent areas	16
Nike Cajun 4	24 Jul 56	<113	...	...	...	...	...	Atlantic off Virginia	13
... 3 in all	7 Jul 58-18 Nov 58	<120	...	...	24.5x18	...	B/W	Manitoba, Hudson Bay	—
Nike-Cajun (HUGO)	5 Dec 58	70-137	16	4.4-8.6	10.5x7.5	47	B/W	Atlantic off Virginia	17
Thor 187	12 May 59	<130	10	<13	10.5x7.5	58	B/W & color	Atlantic S.E. of Florida	18
Thor 202	24 Jul 59	<585	5.7	<100	10.5x7.5	95			
Atlas	24 Aug 59	370-1400	5.7	65-250	10.5x7.5	95	B/W	Atlantic, West Indies, S. American coast	19,20,21
Aerobees, 5 in all	15 Sep 60-19 May 61	65-225	38	1.7-5.9	57x57	94	B/W, IR, color[6]	Central Canada, Hudson Bay	22,23
Aerobee	17 Jun 63	63-182	150	.42-1.2	57x57	30	IR	New Mexico	—

Mercury photography

Mercury MR1A	19 Dec 60	< 210	75	<2.8	57x57	45	B/W	Atlantic	33
Mercury MR2	31 Jan 61	< 252	75	< 3.4	57x57	45	color	Atlantic, Florida, Bahamas	33
Mercury MR3	5 May 61	< 187	75	< 2.5	57x57	45	color	Atlantic	24,25,33
Mercury MA4	13 Sep 61	158-228	75	2.1-3.0	57x57	45	color	Sahara, E. Africa	26,27,33
			...	...	10.5x7.5	178	color		
Mercury MA5	29 Nov 61	159-237	75	2.1-3.2	57x57	45	color	Sahara, N.W. Mexico, S.E. U.S.A.	33
			...	...	10.5x7.5	...	color		
Mercury MA6	20 Feb 62	160-254	50	3.2-5.1	36.3x24.5	47	color	Oceans, N.W. Africa, Florida	28,29,33
Mercury MA7	24 May 62	160-265	?50	?3.2-5.3	36.3x24.5	?47	color	W. Africa	30,33,34
Mercury MA8	3 Oct 62	161-279	80	2.0-3.5	57x57	54	color	S.W. U.S.A., Mexico, S. America	31,33,34
Mercury MA9	15 May 63	160-267	80	2.0-3.3	57x57	54	color etc.	India, Tibet, Arabia, Africa, etc.	32,33,34

<u>Tiros photography</u>

Tiros I	1 Apr 60- Jun 60	690-750	—[7]	170-190[7]	6.3x6.3[8]	104[8]	TV	55°N to 55°S	35 to 53
			40	17-19	"	12.7	"		
Tiros II	23 Nov 60- Dec 61	620-730	—	160-180	"	104	"	"	
			40	16-18	"	12.7	"		
Tiros III	12 Jul 61- Nov 61	740-820	—	180-200	"	104	"	"	
			—	180-200	"	104	"		
Tiros IV	8 Feb 62- Jun 62	710-840	—	180-210	"	104	"	"	
			5.7	120-150	"	75	"		
Tiros V	19 Jun 62- May 63	590-970	—	150-240	"	104	"	65°N to 65°S	
			5.7	100-170	"	75	"		
Tiros VI	18 Sep 62- ...	680-710	—	170-180	"	104	"	"	
			5.7	120-130	"	75	"		
Tiros VII	Jun 63- ...	...	—	...	"	104	"	"	
			—	...	"	104	"		
Tiros VIII	21 Dec 63- date	...	...	...	...	...	"	...	

Notes on Table I

1. ... means not available.
   — means not applicable.
   ? means implied.

2. When the values of focal length and acceptance angle are not both available, one has been calculated from the other using:-

$$\theta = 2\tan^{-1}\frac{\sqrt{a^2+b^2}}{2f}$$

where θ is the angle of view, f is the focal length, and a and b are the dimensions of the frame. The angles of view given are referred to the full diagonal of the frame.

3. The following correspondences between film size and frame size have been assumed here:

16mm. movie	10.5 x 7.5 mm.
35mm. movie	24.5 x 18.0 mm.
35mm. still	36.3 x 24.5 mm.
70mm.	57 x 57 mm.
"4x5 inch"	127 x 102 mm.

4. Abbreviations have the following meanings:

B/W	Black-and-white
IR	Infra-red
TV	Television

5. In addition to these published references, this table incorporates information from correspondence or unpublished reports from several individuals mentioned in the acknowledgments.

6. Some with polarising filter.

7. Because of the large optical and electronic distortions, focal length is not a very meaningful measure for the Tiros TV camera systems, especially the wide-angle system. The nominal focal length of the wide angle lenses is 5.0 mm. The scales given here are based on f = 4.0 mm. The frame size and angle of view are consistent with f = 3.5 mm.

8. Frame size and angle of view figures for Tiros cameras are referred to the corners of the scanned area of the vidicon tube, not to the engraved fiducial corners. (Erickson and Hubert, op. cit., p.7 - see footnote 20 to text)

FIGURE CAPTIONS

Fig. 1. Photograph taken from V2 rocket no. 40, roughly 80 km (50 st. mi.) above White Sands Proving Ground, New Mexico. Fired 1103 M.S.T. 26 July 1948. 4 x 5 inch negative. Super-XX film (panchromatic) with Wratten 25A filter (transmits red). f = 161 mm, giving 53° angle of view. $^{1}/500$ sec. at f/8. Credit: Johns Hopkins University Applied Physics Laboratory. View towards north. The black, lake-like feature in the foreground is a lava flow. A road can be seen crossing it at one point. The dark line east of the lava flow is a railway, the white line beside it a main road. Forests on the Sierra Blanca and San Andres Mountains, east and west of the lava flow, appear dark. The remainder of the area is desert or semi-desert.

Fig. 2. Photograph taken from Viking 12 rocket. Frame no. 29. 228 km (142.5 st. mi.) above sea level. Fired 1455 M.S.T., 4 Feb 55, from White Sands Proving Ground. For other details see text and Table I. Credit: U.S. Naval Research Lab. Infrared film with Wratten 25A filter (red). $^{1}/500$ sec. at f/8. In the foreground is the basin-and-range area of Arizona. The Gulf of California, Lower California, and the Pacific Ocean are in the distance. The dark area N.E. of the Gulf is an outcrop of volcanic rock. The irrigated areas near Phoenix appear in the foreground, and of the Imperial valley in the background. Other features which can be picked out include several reservoirs, the Salton Sea, the southern part of the central valley of California, the trace of the San Andreas fault, and the smoke pall over Los Angeles.

Fig. 3. Photograph taken from Aerobee rocket NASA 4.87, roughly 160 km (100 st. mi.) above White Sands Proving Ground. Camera 1, frame 191. Fired about noon, 17 June 63. 70 mm. Kodak Aerographic infrared film with Wratten 25A filter (red). $^{1}/1000$ sec. at f/11. f = 150 mm, giving 30° angle of view. Credit: NASA Sounding Rocket Division. The city of El Paso is at the top of the picture (north). A ribbon of irrigated cultivation extends southeastward from it along the Rio Grande. Just N.E. of El Paso are the runways of two airfields. The lines radiating from the city represent both roads and railroads. Ranges of hills and intervening basins can be seen in the S.W. (Mexican) half of the photo.

Fig. 4. Photograph taken during Mercury unmanned orbital flight MA-4. Frame no. 187. Height 164 km (102 st. mi.) above position 25°54'N lat., 11°33'W Long. Time of exposure 1423 G.M.T., 21 July 61. Principal axis of camera was inclined 61° from the vertical and pointed in direction N24°E. 70 mm. Anscochrome color film. 1/500 sec. at f/8. f = 75 mm. Field of view 45°. Credit: NASA Manned Spacecraft Center. The entire Atlantic coast of Morocco is visible, and Spain is just distinguishable in the extreme distance. The white area on the left is a layer of low cloud which stops abruptly at the coast. Other clouds outline the several ranges of the Atlas Mts. The most distant line is probably over the Sierra Nevada in Spain. Narrow strips of vegetation follow some of the wadis flowing to the coast, but otherwise the patterns are predominantly geological. The foreground represents the outcrop of a series of Paleozoic rocks dipping to the S.S.E. The more resistant rocks, sandstones and limestones, stand out as ridges up to 200 m (700 ft) high, while schists and shales underlie the intervening vales. Small folds with axes SW-NE have in places produced zig-zag outcrops or dome-and-basin structures. The light tone of the depressions is due to Quaternary deposits of sand, gravel and lacustrine limestone.

Fig. 5. Photograph taken during Mercury unmanned orbital flight MA-4. Frame no. 198. Height 166 km (103 st. mi.) above position 24°16'N lat., 7°13'W long. Time of exposure 1424 G.M.T. 21 July 61. Principal axis of camera was inclined 50° from the vertical and pointed in direction N20 1/2°E. Camera details as for fig. 4. Credit: NASA Manned Spacecraft Center. The longitudinal dunes of the Erg Iguidi appear in the foreground, trending parallel to the dominant northeasterly wind. The right foreground is part of the Eglab massif, composed of pre-Cambrian crystalline rocks with small areas of dark volcanic rocks. The parallel white stripes left of the dunes are salt flats. The light area in the middle distance is the Hamada du Dra, composed of late Pliocene rocks, mainly limestone.

Fig. 6. Photograph taken during Mercury unmanned orbital flight MA-5. Frame no. 94. Height about 158 km (98 st. mi.). Position about 32°N lat., 90°W long. Photograph taken 1 hour 35 minutes after launch, 29 Nov. 61. View west. 70 mm Super Anscochrome color film. 1/500 sec. at f/6.3. f = 75 mm. Field of view 45°. Credit: NASA Manned Spacecraft Center. The white area in the background is an area of stratus cloud lying over Texas. The edge of the cloud is approximately along the Texas/ Louisiana boundary. The area visible is northwestern Louisiana, and the foreground is part of the Mississippi-Red River delta. Dark areas on the ground are forested, while light-areas are not. Over most of the area shown, the courses of rivers and former rivers are followed by bands of non-forested land. The most conspicuous band follows the Red River. The southern part of the area shown is generally grassland, and forest occurs only along the streams. The rivers themselves are not easily visible, but in the right foreground two lakes appear, Larto Lake, an ox-bow lake, and Catahoula Lake.

Fig. 7. Picture taken by Tiros IV camera 1 (wide angle) on orbital pass 999 at 0305 G.M.T. on 19 April 1962. The central cross is at 46 1/2°N lat. and 130°E long. 1. Lake Khanka. 2. River Amur. Both of these are ice-covered. 3. Sea of Japan. 4. Vladivostok. 5. Harbin. 6. Clouds.

Fig. 8. Picture taken by Tiros IV camera 2 (medium angle) on orbital pass 568 at 0330 G.M.T. on 20 March 1962. The central cross is at 32°S lat. and 145°E long. 1. Great Australian Bight. 2. Tasman Sea. 3. Murray Lowlands with areas of irrigated land. 4. Adelaide.

Fig. 9. Picture taken by Tiros IV camera 2 (medium angle) on orbital pass 1203 at 0815 G.M.T. on 3 May 1962. The central cross is at 25 1/2°N lat. and 14 1/2°E long. The tone variation illustrates three different types of rocks; young volcanics, tilted Paleozoic sediments, and young sand or gravel deposits. 1. El Haruj el Aswad. 2. Jebel el Sauda (both Tertiary and Quaternary volcanic areas). 3. Amsak (chain of Paleozoic rocks separating basins of Edeyins). 4. Tassili N'Ajjer (plateau of gently dipping Paleozoic rocks). 5. Mangueni Plateau. 6. Plateau du Djado (both composed of nearly horizontal Paleozoic sandstones, schists and diabases). 7. Edeyin Murzuq. 8. Edeyin Ubari (dune-filled basins). 9. Serir of Tibesti (gravel surface). 10. Erg d'Admer (dune area).

Fig. 10. Picture taken by Tiros I camera 1 (narrow angle) on orbital pass 724 at 0813 G.M.T. on 21 May 1960. The central cross is at $42^{1}/2^{o}$ N lat. and 78^{o}E long. 1. Eastern half of Issyk Kul', a salt lake, surface elevation 1609 m.. The reason for the variation in tone within the area of the lake has not been established. 2. Snow-covered mountain ranges, part of the Tien Shan, rising above 5000 m. in places. 3. Dark areas are valleys and lowlands free of snow. 4. Valley of the Uch Kul.